THEORETICAL INVESTIGATION OF GAS MANAGEMENT IN ZERO-GRAVITY SPACE MANUFACTURING

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ABSTRACT

The proposed research has as its objective the management of gases in liquefied materials in a free suspended position in zero gravity environment. The investigation shall mainly center on the degassing of liquefied materials, which shall be accomplished by accelerating the material. Also the gas-liquid-interaction, as well as methods to distribute gas properly in liquefied materials of various viscosity and surface tension shall be studied.

INTRODUCTION

The advent of space flight and the availability of large boosters which can carry large payloads into an orbit make it possible to put a workshop in space in which intriguing manufacturing processes could be performed. The lack of gravitation and the vacuum are the basis for the development of unique technologies which are absolutely impossible in an earth bound workshop. It is believed that one is able to cast perfect optical lenses, to produce perfect ball bearings and even more, to create unique materials, alloying various metals or by mixing gas in any ratio into liquefied materials. For such applications the gas bubbles have to be managed in a certain fashion according to the purpose of the process.

In most manufacturing processes the degassing of the material during the liquid phase is a basic requirement for obtaining a useful engineering material. On earth this is aided by buoyancy forces which cause the entrained gas bubbles to rise to the surface and escape. This process can be accelerated and enhanced by degassing into a vacuum. In an orbital workshop, however, buoyancy forces are not available and the elimination of gas bubbles from the molten material

may be a serious problem. In order to introduce forces which move the gas bubbles, the molten material is placed in an acceleration force field. The centrifugal force field will create a migration of the bubbles towards the rotational axis and shall finally give the total gas bubble as well as the spinning free floating material a certain shape which depends upon the angular velocity, the volume, the viscosities, densities and surface tensions involved. The stability of the system is also of importance.

Taylor[1] treated the behavior of a gas bubble in an infinite liquid region and determined the shape of a bubble in an axisymmetric electrical field under the action of surface tension, neglecting gravitational effects. He found that due to the electric field the originally spherical bubble was deformed into a convex body of revolution. The shape of a rotating drop under the influence of capillary force was treated by Lord Rayleigh[2], while Rosenthal[3] investigated the shape of a bubble in one liquid inside a denser body of liquid which rotate rigidly together. In both studies gravity has been neglected. The stability of the system has also been discussed. It was found that the bubble length increases almost linearly with its volume and that it increases proportionally to the four-thirds power of the angular velocity. With increasing angular velocity the bubble flattens at the equator and the length, (measured along the spin-axis) increases. For constant speed of rotation and increasing bubble volume, the bubble elongates, its radius approaches a limit value and its length increases.

Habip, Siekmann and Chang[4] investigated the effect of an electric field upon a uniformly rotating drop in a dielectric liquid mass under the influence of surface tension. The axisymmetric relative equilibrium shape of the bubble in such a uniform axial electric field has been determined. The shape of the bubble is a function of the dielectric constants, the surface tension as well as the rotational speed of the system. In another study Pao and Siekmann[5] investigated the oscillations of a vapor bubble in a rotating cylindrical container in zero gravity.

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1. G. I. Taylor, "Studies in electrohydrodynamics. I. The circulation produced in a drop by an electric field." Proc. Royal Soc. A, Vol. 291, pp. 159-166 (1966).
2. Lord Rayleigh, "The Equilibrium of Revolving Liquid under Capillary force." Philos. Mag. S.6., Vol. 28, No. 164, pp. 161-170 (1914).
3. D. K. Rosenthal, "The shape and stability of a bubble at the axis of a rotating liquid." Journal of Fluid Mechanics 12, pp. 358-366 (1962).
4. Habip, L. M., Siekmann, J. and Chang, S. C., "On the Shape of a Rotating Liquid Drop in an Electric Field." Acta Mechanica, Vol. IV, 1, pp. 107-114 (1967).
5. Pao, S. K. P., Siekmann, J., "Oscillations of a vapor cavity in a rotating cylindrical tank." J. Fluid Mechanics, Vol. 31, Part 2, pp. 249-271 (1968).

Since the stability of the bubble depends largely upon the rotational speed of the system, the influence of it upon the shape of the bubble and the natural frequencies of the liquid system have been determined. It was found that the rotational speed had a profound effect on the dynamic response of the liquid-gas-interface. Under the presence of a small gravity field the response of a gas-liquid system in a cylindrical container has been investigated[6]. Small amplitude free oscillations of an incompressible liquid of arbitrary depth have been treated, and the natural frequencies have been determined for small and very large angular velocities. A similar investigation has been performed for a harmonically excited rotating system[7], where wave form of the liquid surface as well as the response of the system have been determined.

DISCUSSION OF THE PROGRAM PLAN

The proposed program of research in theoretical investigation of gas management is planned in three phases:

Phase I: Degassing of materials during their liquid phase.

Phase II: Migration of a bubble during the action of a centrifugal force field.

Phase III: Distribution of gas in a liquefied material.

PHASE I: DEGASSING OF MATERIALS DURING THEIR LIQUID PHASE

The objective of this phase is the determination of the shape of a gas bubble as well as the shape of the liquid containing this bubble under the influence of surface tension, chamber pressure of the material, and the rotational speed of the system. The study will consider the critical velocity and the critical volume under which the system starts to disintegrate. In this phase the effect of the gravity gradient shall be neglected. The treatment of such a doubly-connected liquid-gas-geometry is based on the interaction of the contribution of pressure due to surface tension and centrifugal force. On the gas-liquid-interface one must consider the potential of the surface tension σ_{ij}. Furthermore, the internal pressure should equilibrate the external pressure, which is

6. Bauer, H. F., "Liquid Oscillations in a rotating container." Project B-906, NASA-Research Grant No. NGR-11-002-028 (1966).

7. Bauer, H. F., and Chang, S. S., "Dynamics of Propellant in a Spinning Container," (in preparation).

assumed constant. The shape of the interface is then governed by the following expression:

$$p_i = p_{i-1} + \frac{1}{2}\rho_i \Omega^2 r^2 + \sigma_{i-1i}\left(\frac{1}{R_{i-1i}} + \frac{1}{R'_{i-1i}}\right) \quad , \quad i=1,2,3$$

where R_{ij} and R'_{ij} are the radii of curvature of the surface of the interface of medium i and j . Medium 1 represents the interior gas bubble, medium 2 the liquefied material and medium 3 the chamber gas. The angular velocity of the system is denoted by Ω, while r represents the distance of a particle to the axis of rotation. σ_{ij} is the surface tension of the interface (ij) , while ρ_i (i = 1, 2, 3) represents the mass density of gas, liquid and chamber gas respectively. These equations determine the equilibrium of the gas-liquid-interface as functions of the parameters of the system. They have to be solved for a given volume of material for various amounts of entrained gases.

Location and geometric shape of the gas bubble as well as the geometrical shape of the liquefied material and the critical rotational speed shall be determined.

PHASE II: MIGRATION OF A BUBBLE DURING THE ACTION OF A CENTRIFUGAL FORCE FIELD

A free suspended liquid material contains a gas bubble. In order to move those bubbles to a proper degassing position, the system is put into rotation. Before attacking the dynamic problem of the migration of a gas bubble under the influence of surface tension, viscosity and centrifugal forces, the time involved for the motion of the gas under the sole effect of Newton's gravitational attraction force shall be studied first. The objectives of the second part of this phase is then the investigation of the flow of the total system under the action of centrifugal forces of various magnitudes. Thus the time necessary to move gas from a certain location in the liquefied material to the degassing position should be determined. Critical speed and volume shall be taken into consideration as limit factors of such a process, in order to obtain reasonable time durations for the migration of the gas bubble. In the first approximation the bubble during its migration is considered as a perfect sphere, of which, of course, the volume change during the motion of the bubble shall be observed.

PHASE III: DISTRIBUTION OF GAS IN A LIQUEFIED MATERIAL

In this phase the response of a gas bubble in a rotating system under the action of harmonic excitation of the total system shall be attempted. Some thought will be given to the even distribution of gas bubbles in a liquefied material. For this reason the action of an electric field may be of benefit.